A review of radiometers used for Fiducial Reference Measurements used for Satellite Radiometric Validation

"Do we know enough about our instruments to complete an uncertainty estimate?"

Presented by Kevin Ruddick (RBINS) at FRM4SOC Final Workshop, 2018-10-04
with support from FRM4SOC partners and instrument manufacturers
(Biospherical, CIMEL, IMO, Satlantic/Seabird, TRIOS, WaterInsight)

What is known about existing radiometers? (for making a uncertainty budget)

	Instrument #1	Instrument #2	Instrument #3	… …
Spectral response and wavelength calibration				
Spectral straylight/Out of band response				
Radiometric calibration (and immersion factor)				
Radiometric noise				
Radiometric linearity				
Thermal stability				
Angular response (cosine for Ed)				
Polarisation sensitivity				

How well do you know your instruments?

Can you fill this Table with references?

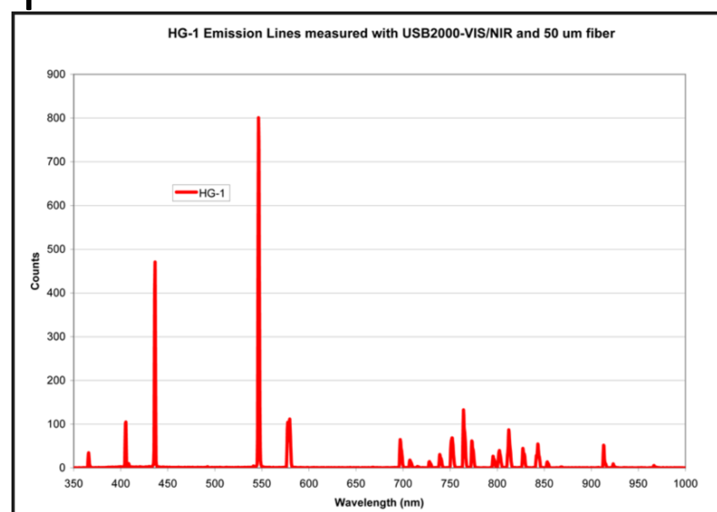
… and estimate an uncertainty budget for your instrument?

Instruments studied

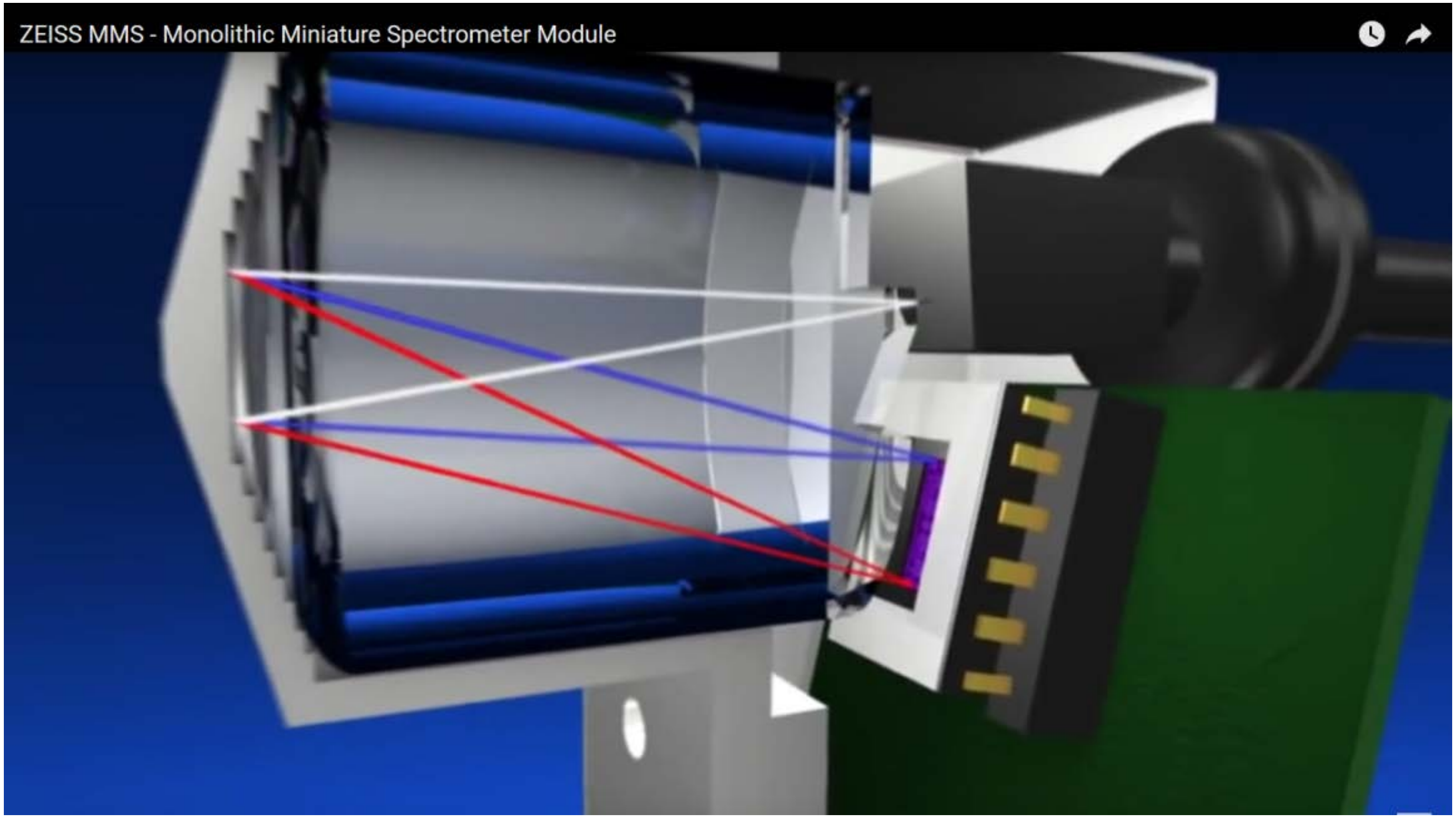
- Biospherical/C-OPS
- CIMEL/SeaPRISM
- IMO/DALEC
- Satlantic OCR500
- Satlantic HyperOCR
- TRIOS/RAMSES
- WaterInsight/WISP

Spectral Response function and wavelength calibration

- Spectral response function usually defined via:
  - Central Wavelengths and FWHM (per detector/filter)
  - OR full spectral response function
- Symmetrical and ~ Gaussian (spectrometers) or square (filters)
- Often specified by component suppliers
  - e.g. Zeiss MMS1 spectrometer or filter manufacturers
- Sometimes checked by instrument suppliers
  - e.g. WISP OceanOptics HG-1



Spectral straylight - spectrometers

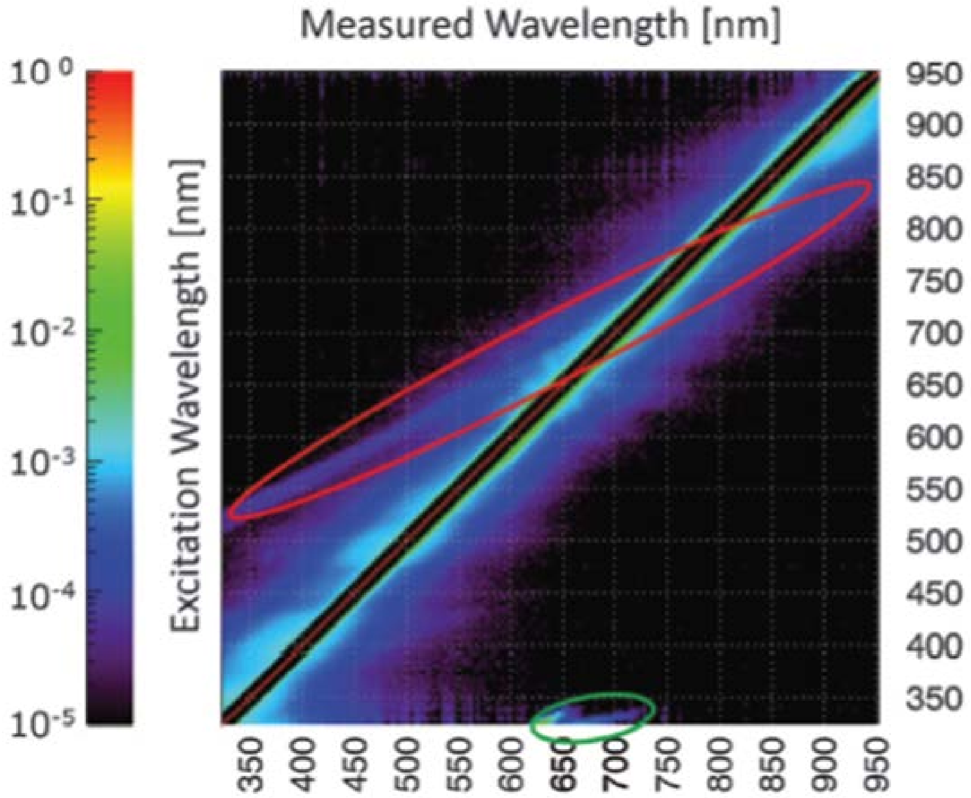


[Zeiss MMS1 spectrometer diffraction grating – see Youtube]

Imperfections (e.g. secondary reflections) can cause photons with wavelength λ_1 to reach detector of wavelength λ_2 : (spectral) straylight

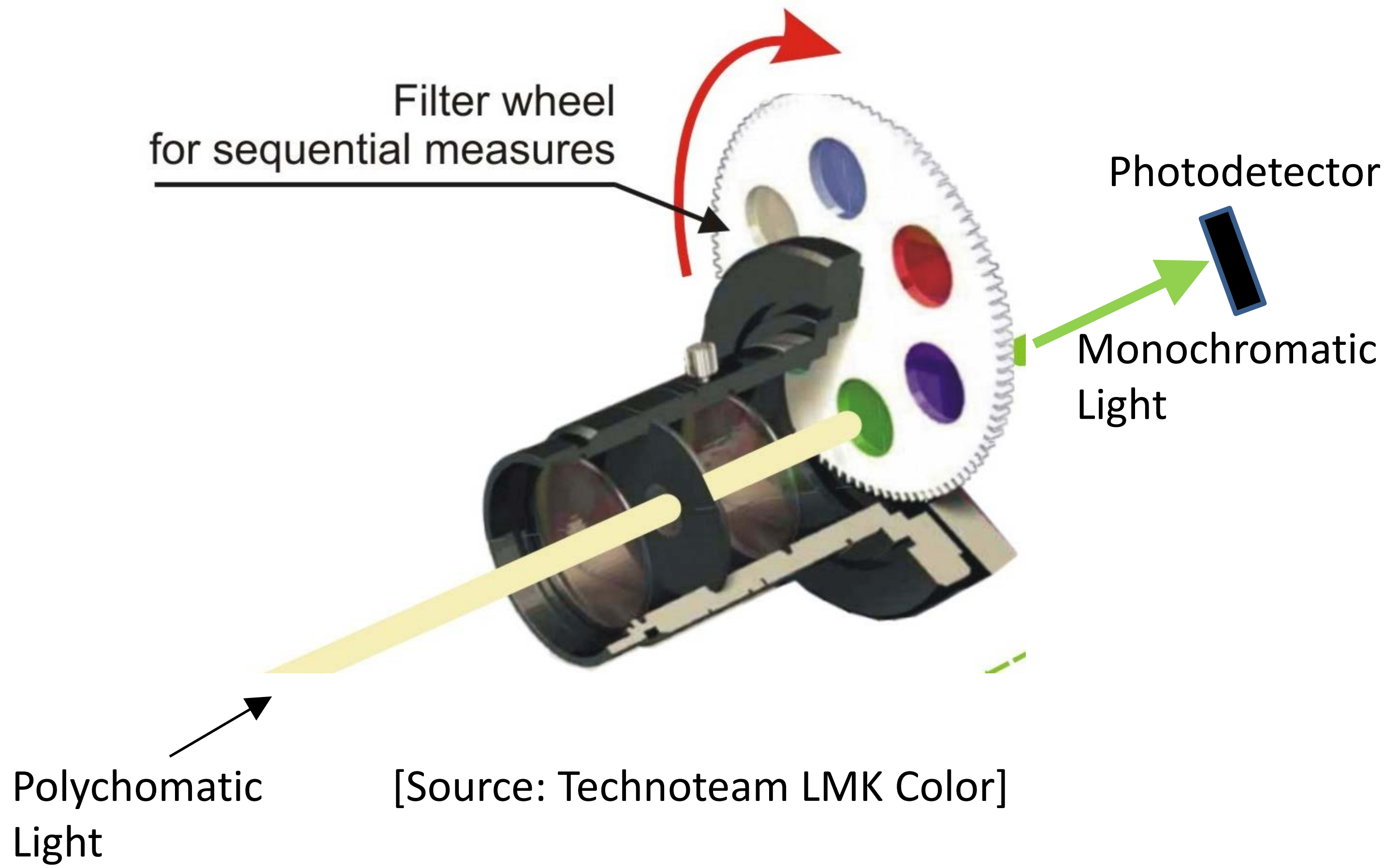
Spectral straylight - spectrometer

- e.g. Test results available for Zeiss MMS1 and OceanOptics JAZ spectrometers



Straylight Distribution Function matrix for a TRIOS/RAMSES radiance sensor – see [Talone et al, 2016]

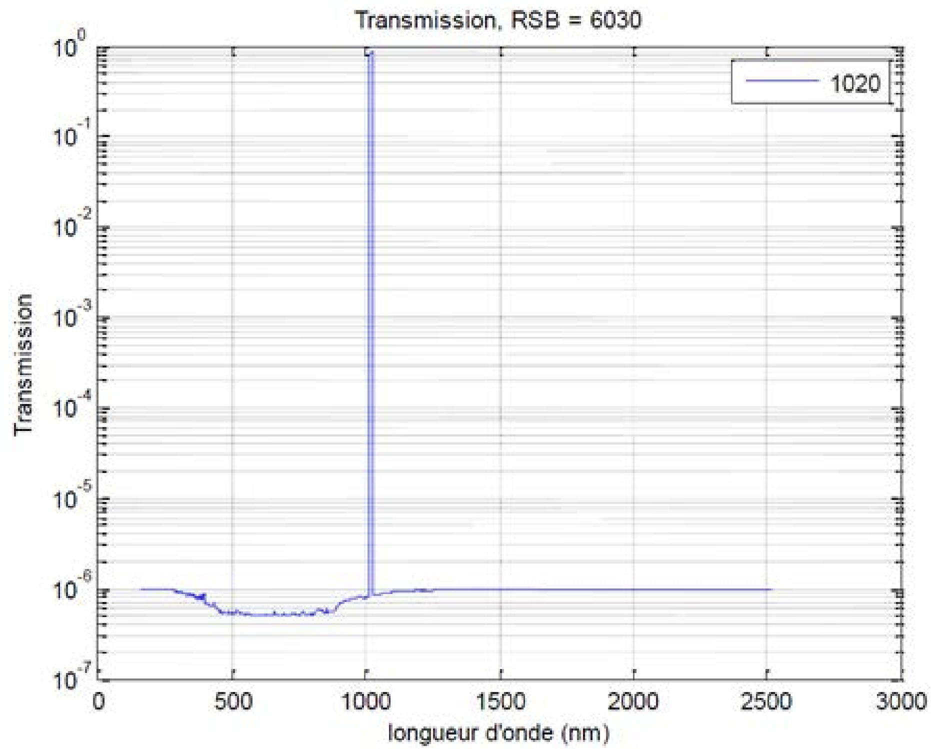
Spectral out of band response – filter wheel radiometers



[Source: Technoteam LMK Color]

Spectral out of band response – filter wheel radiometers

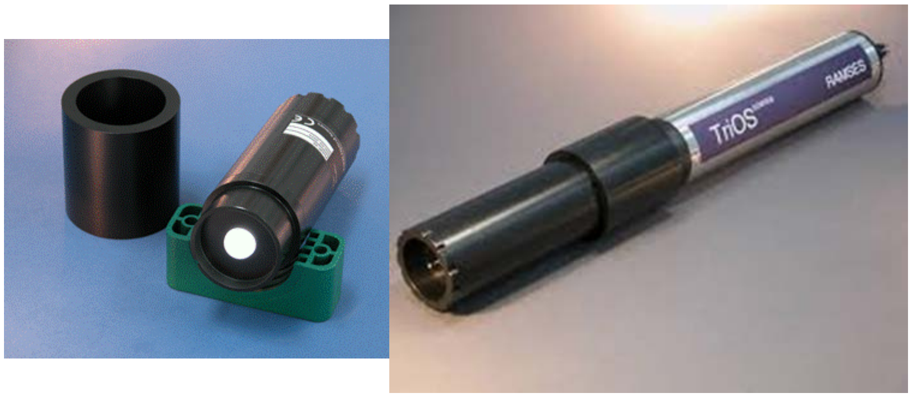
- Component specifications, e.g. spectral response function of filter [CIMEL Electronique]



- Can be validated for whole instrument with tunable laser

Radiometric calibration

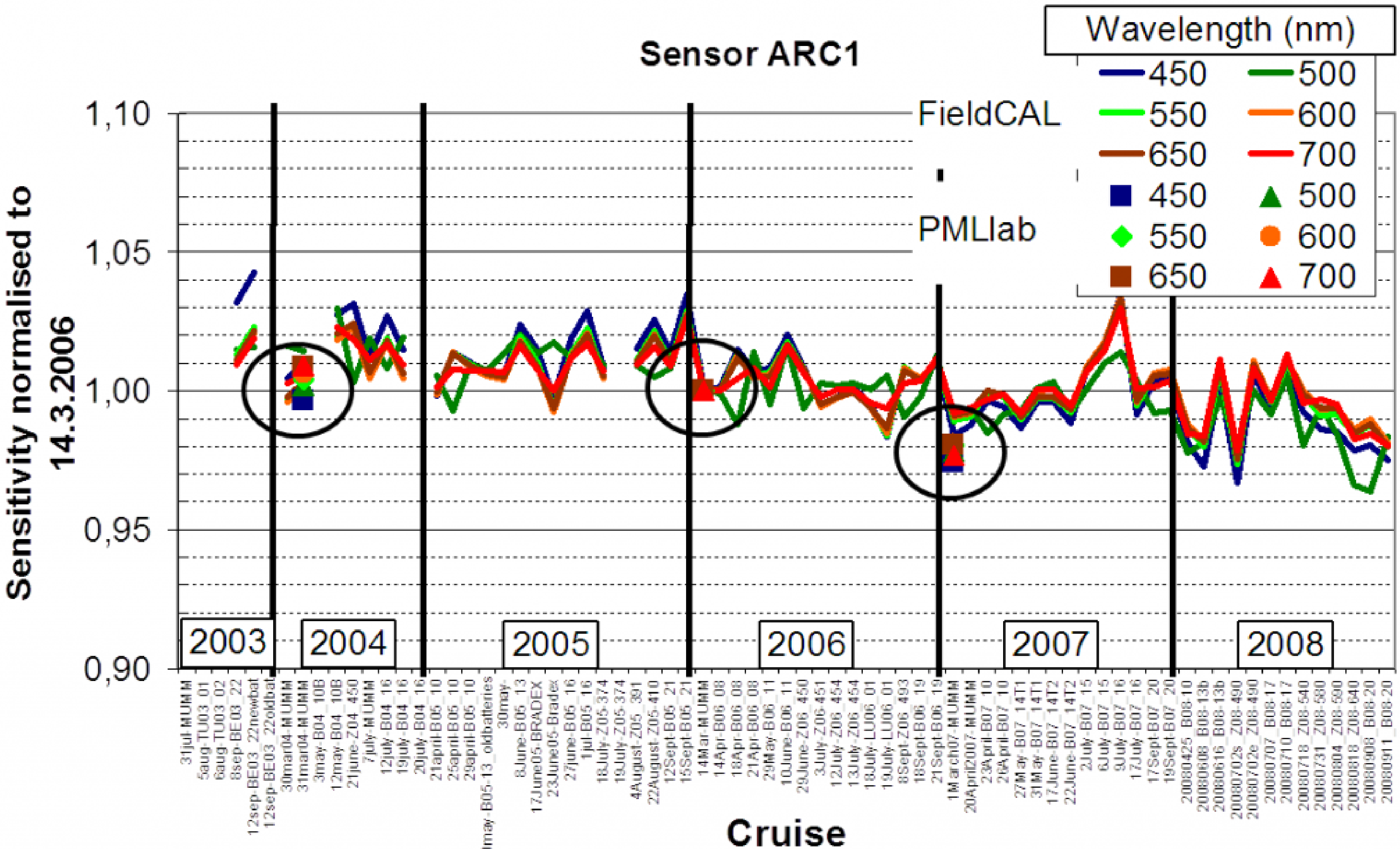
- Laboratory absolute calibration investigated in FRM4SOC laboratory intercomparison (LCE-1 and LCE-2) activities
- Temporal variability of radiometric sensitivity can be followed for some instruments with portable calibration devices



TRIOS/FieldCAL

OceanOptics LS-1 (WISP)

Example calibration time series [RBINS: LABcals+TRIOS/FieldCALS]



(but beware that these calibration devices have their own uncertainties: thermal sensitivity, positioning sensitivity, etc.)

(also recommend intercalibration checks)

HIGHROC intercomparison, NIVA (Oslo), 2015

IAFE/RBINS intercomparison, Buenos Aires, 2017

Immersion factor for underwater measurements

- In-water calibration different from in-air e.g. [Zibordi and Voss, 2014]:
  - Irradiance, E: reduced transmittance of water-diffuser interface (each sensor individually!)
  - Radiance, L: decrease in solid angle FOV, increase in transmittance of optical window (less inter-sensor variability)

Radiometric noise and Dark current

- If no light enters sensor there is still:
  - Slowly-varying signal (“dark current”)
  - Fast-varying signal (“noise”) and digitisation
- BOTH may depend on temperature and integration time
- Various strategies for “dark current” removal:
  - Internal shutters or opaque filter in wheel, OR
  - (spectrometer) “dark pixels” not illuminated
  - THEN remove this signal (with same integration time) from measurement
- “Noise” should be kept negligible in uncertainty budget

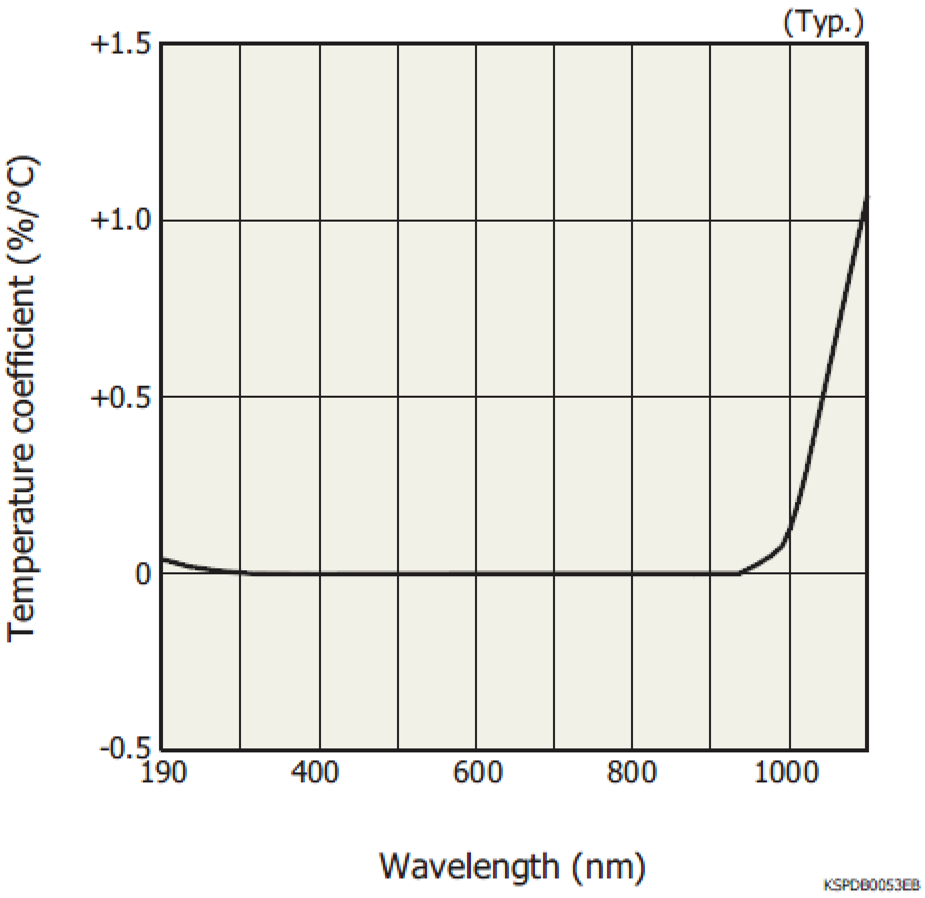
Radiometric linearity

- Spectrometers and photodetectors may have non-linear response with increasing signal, especially near saturation
  - E.g. (Hamamatsu) "as long as the output is within 95 % of the saturation charge, the linearity error can be held to a small value by using an external circuit in the current-integration readout mode". Severe non-linearity problems occur above 95% of the saturation limit, which is avoided in by reducing integration time when necessary.
- Difficult to find any validation test information
- Some new results during FRM4SOC project

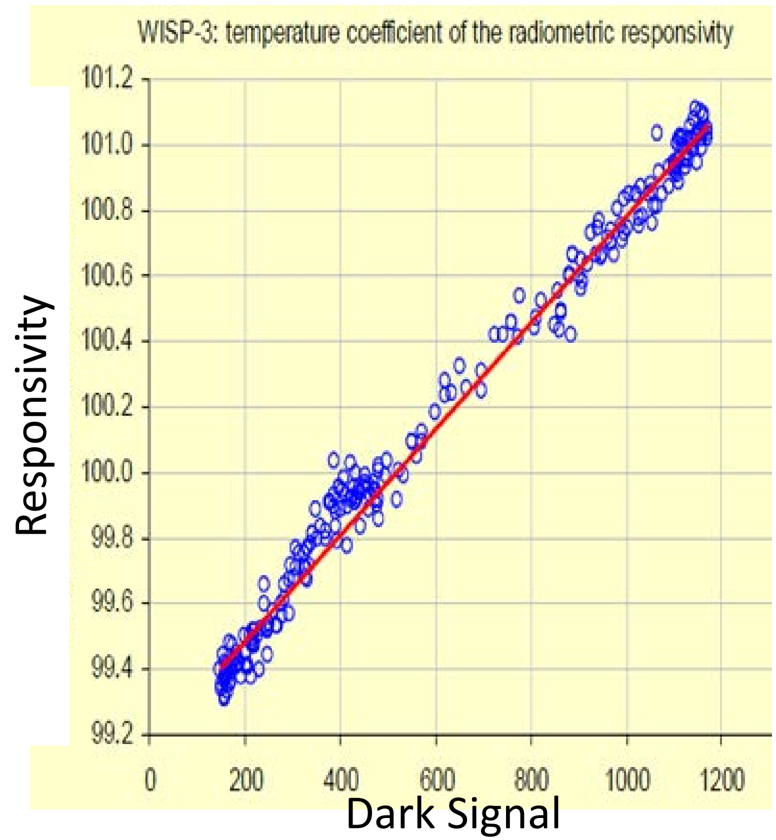
Thermal stability

- Electronic components (photodetectors, ADC, etc.) often sensitivity to temperature:
  - A) Dark Current
  - B) Responsivity
- Thermal regulation of instrument is possible but very expensive (OSPREY)
- Thermal characterisation of instruments allows correction to reduce uncertainties
  - Time lag with ambient temperature?
  - Internal temperature reading?
  - [JRC, Tartu, Australia/IMO tests]

Thermal sensitivity - examples



e.g. Hamamatsu S1336 photodetector (CIMEL/SeaPRISM)

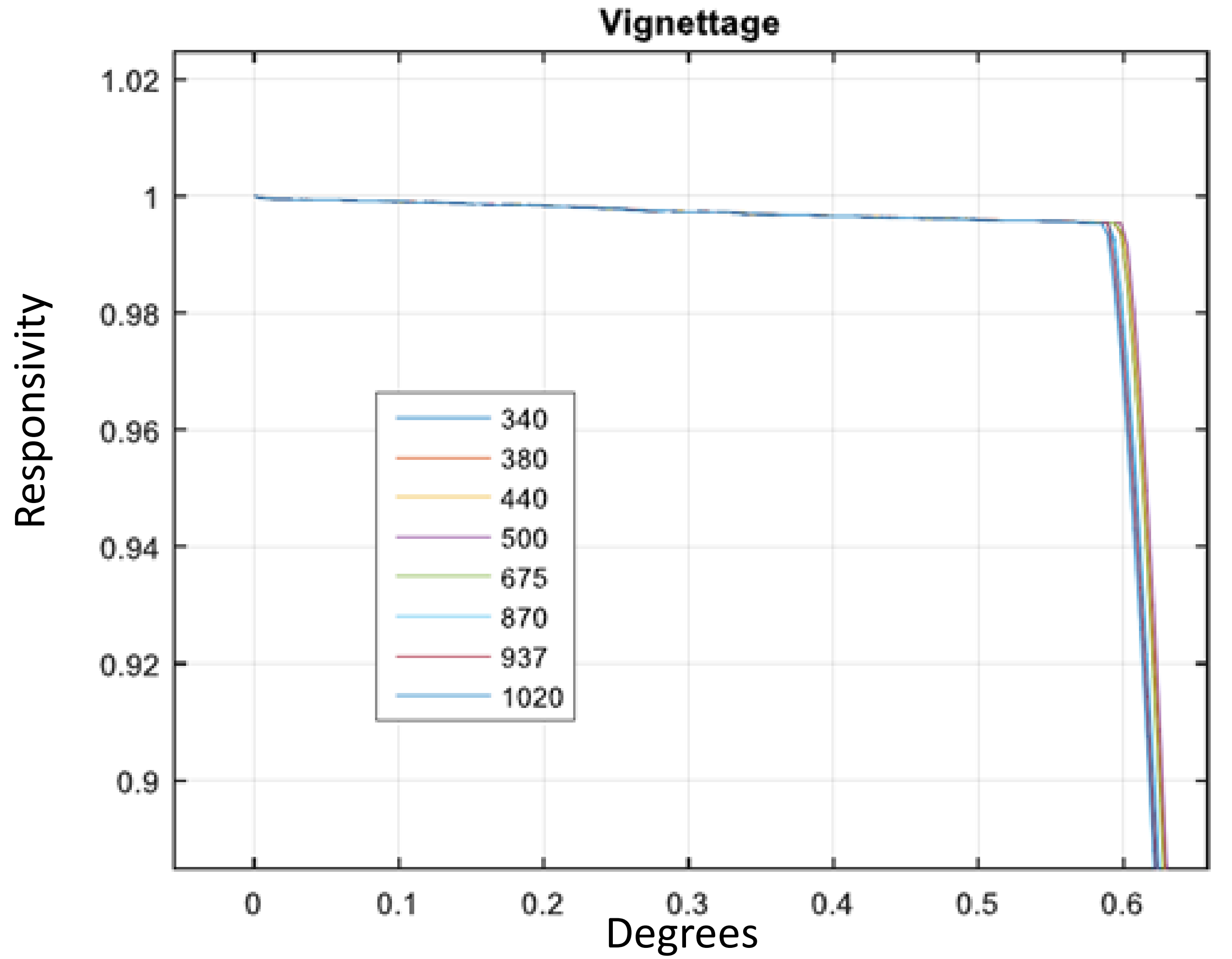


Tests on WISP-3 spectrometer [Ghezehegn et al. 2015]

Angular response - radiance

- Generally specified as FWHM Field of View, but could be checked…

[CIMEL Electronique]

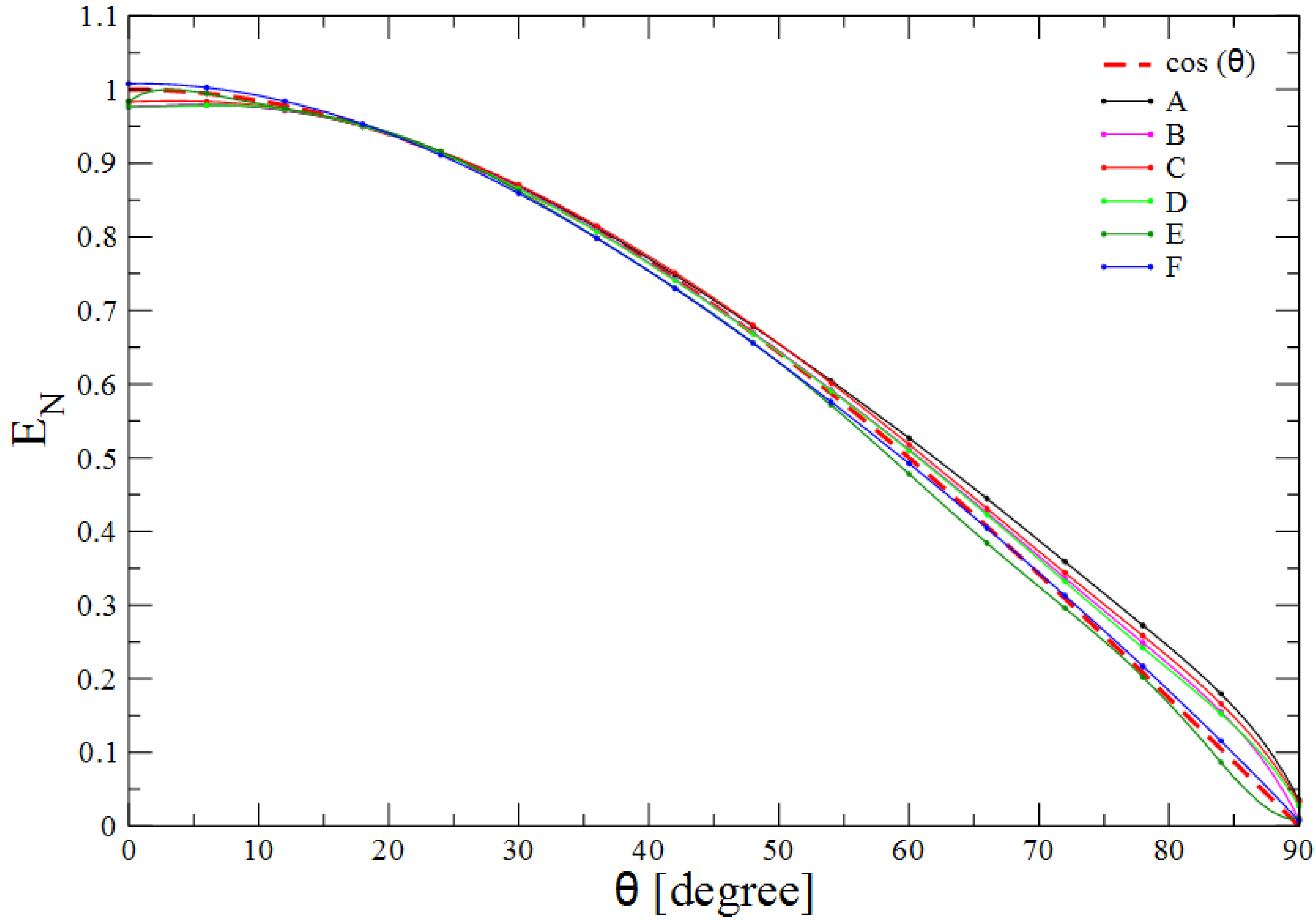


Angular response - irradiance

- Depends on diffuser head geometry and material
- Each unit is different …

6 TRIOS RAMSES-ACC irradiance sensors

Normalised at 20°
In air



[Mekaoui, S, and G Zibordi. 2013. "Cosine Error for a Class of Hyperspectral Irradiance Sensors." Metrologia 50 (3): 187–99. doi:10.1088/0026-1394/50/3/187.]

Polarisation sensitivity

- Mirrors have significant polarisation sensitivity

… and the sea surface is highly polarised at 40°

- Diffusers, fibre optics decrease polarisation sensitivity
- Polarisers may also be

used to block air-water

(“skyglint”) reflection

SIMBADA sunphotometer/radiometer (R. Frouin)

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Characterisation of radiometers

- Good response/information from:
  - Biospherical/C-OPS
  - CIMEL/SeaPRISM
  - IMO/DALEC
  - Satlantic/Seabird-HyperOCR+OCR500
  - TRIOS/RAMSES (inc. JRC and TARTU tests)
  - WaterInsight/WISP
- BUT some characteristics may be unit-specific … and very time-consuming to characterise
- Draft report discussed and approved by manufacturers at Sept2017 workshop, publicly available from www.frm4soc.org
- Update planned for Dec2018 - any new tests/doc?